

## **Interference into ATG from Incumbent Users of the 14.0-14.5 GHz Band**

### **1.0 Introduction**

The purpose of this document is to examine whether Qualcomm's proposed air-to-ground ("ATG") service could offer a viable service given the interference environment it would be presented by incumbent users of the 14-14.5 GHz band. Specifically, this document analyzes interference from GSO FSS and AMSS into the proposed ATG service.

### **2.0 Need for Three-Dimensional ATG Antenna Masks**

There is a need for Qualcomm to provide three-dimensional antenna pattern masks for its GS and aircraft antennas in order for proper sharing analyses to be performed.

In its July 31, 2012 Reply Comments, Qualcomm makes the following statement:

"A Qualcomm-specific antenna pattern for the GS and the aircraft antennas is not needed to perform interference calculations. In fact, providing antenna masks for the purpose of interference calculations and FCC rule making is in keeping with the Commission's practice."

We wholeheartedly agree with Qualcomm's second sentence, because it is actually in keeping with the Commission's practice, but because Qualcomm argues that there is no need to provide such masks, we conclude that the second sentence was meant to have a "not" in it.

In a nutshell, Qualcomm argues that there is no need to provide such antenna pattern masks because the FCC will develop rules that protect the incumbent users of the 14-14.5 GHz band. Qualcomm fails however to consider the role and responsibility that the FCC has in allocating a new service to a band, whether it be co-primary or secondary. Any newly proposed service must be subjected to proper sharing analyses in order to determine whether it can share the band with incumbent users. Proper spectrum management principles include assessing the interference from incumbents into the newly proposed service as well. In other words, before allocating a new service, it is necessary to demonstrate that the newly proposed service can be viable given the interference environment created by incumbent users. Accordingly, it is necessary for Qualcomm to provide three-dimensional antenna pattern masks in order for incumbents and others to assess the interference from existing users of the band into the proposed ATG service.

### 3.0 Interference from a Single VSAT into the ATG Ground Station

On the return link, the ATG ground station (“GS”) receives transmissions from the ATG aircraft. The GS antennas point northwardly. In this section, two cases are presented that demonstrate the ATG return link cannot close its link (i.e., the link is disrupted), due to interference from a single VSAT, at least for the scenarios presented. If there is no return link service, there can be no forward link service, even if it were to be shown that the forward link is viable in the face of FSS interference, because the GS does not receive the user’s request to access a particular website. No return link equals no forward link as well.

Table 1 shows a case where a single VSAT is 16 km away from the GS. Both the VSAT and GS are assumed to be at a height of 30 m above the ground. The VSAT terminal is assumed to be located on a building. The VSAT and GS are assumed to be on the same longitude with the VSAT located north of the GS and the VSAT has an elevation angle of approximately 38.2 degrees to its satellite. The VSAT is assumed to be transmitting with the maximum uplink input density allowed by Section 25.134 of the FCC rules for routine processing of VSAT terminals. The bandwidth of the FSS carrier is assumed to be 2 MHz and there is line-of-sight between the VSAT and GS antennas (i.e., no signal blockage).

The minimum stated  $C/(N+I)$  for the ATG return link is 4 dB. Qualcomm states that this value is for its highest data rate and that it can accept a  $C/(N+I)$  as low as -9 dB, albeit at a significantly reduced throughput.

Table 1 shows that the  $C/(N+I)$  into the GS for the given assumptions does not allow the return link to be closed, and with a substantial deficit of over 21dB.

Note that Table 1 assumes the GS gain towards the VSAT is at the peak GS gain of 37 dBi. The angle subtended at the GS antenna towards the VSAT is approximately 0.07 degrees below the GS station’s local horizon. Qualcomm states that they will use a GS antenna that uses an isoflux pattern in elevation, such that the antenna will have its maximum gain at the lowest-served elevation angle. The lowest elevation angle will occur when the aircraft is at its furthest serviceable distance from the GS which is 300 km. This geometry leads to a peak GS gain of approximately 0.56 degrees above the local horizon. Assuming the GS antenna is pointed at this elevation angle, and with the VSAT location being slightly below the GS antenna’s local horizon in this scenario, it is possible that GS antenna gain may be a few dB lower than that stated in Table 1, but even if this were the case, it would not change the overall conclusion that the return link is severely disrupted. In the absence of three-dimensional GS antenna pattern masks, it is not possible to definitively state the GS antenna gain towards the VSAT antenna.

Table 1. Case 1 of a single VSAT interfering into an ATG GS.

Parameter	Value	Units	Comments
Frequency	14.25	GHz	
Distance between FSS and GS	16	km	Approximately 10 miles
FSS Tx Input Power	13.0	dBW	-50 dBW/Hz in a single 2 MHz carrier
FSS Gain towards GS	-7.5	dBi	$32-25*\log(38.1^\circ)$
GS Antenna Gain	37	dBi	
Free Space Path Loss	139.6	dB	Line-of-sight
Atmospheric Loss	0.16	dB	
Polarization Mismatch	-0.5	dB	
GS Receiver Noise Temperature	794	K	
ATG Return Link Bandwidth	63.0	dB-Hz	
Boltzmann Constant	228.6	dB/K/Hz	
I/N of FSS interferer at GS	38.8	dB	Extremely high I/N
ATG C/N	8.7	dB	
C/I	-30.1	dB	
C/(N+I)	-30.1	dB	Conclusion: No ATG return link service

Table 2 shows a different scenario with the VSAT antenna being located 3 km from the GS station. The VSAT located is on the ground and with a 1 meter height. The GS gain towards the VSAT is assumed to be 20 dB down from the antenna's peak gain of 37 dBi. All other assumptions relative to the Case 1 scenario remain the same. The results for this scenario again show that the ATG return link is disrupted.

Table 2. Case 2 of a single VSAT interfering into an ATG GS.

Parameter	Value	Units	Comments
Frequency	14.25	GHz	
Distance between FSS and GS	3	km	
FSS Tx Input Power	13.0	dBW	-50 dBW/Hz in a single 2 MHz carrier
FSS Gain towards GS	-7.4	dBi	$32-25*\log(37.6^\circ)$
GS Antenna Gain	17	dBi	Uses Qualcomm's assumption of being 20 dB down from 37 dBi
Free Space Path Loss	125.1	dB	Line-of-sight
Atmospheric Loss	0.03	dB	
Polarization Mismatch	-0.5	dB	
GS Receiver Noise Temperature	794	K	
ATG Return Link Bandwidth	63.0	dB-Hz	
Boltzmann Constant	228.6	dB/K/Hz	
I/N of FSS interferer at GS	33.6	dB	Extremely high I/N
ATG C/N	8.7	dB	
C/I	-24.9	dB	
C/(N+I)	-24.9	dB	Conclusion: No ATG return link service

Table 2 uses Qualcomm's assumption that the GS antenna will have 20 dB of discrimination towards a nearby VSAT antenna. This assumption may be overly optimistic considering the angle of the VSAT in Case 2, subtended at the GS antenna with the assumed GS peak gainpointing direction, is only approximately 1.1 degrees from the GS antenna's main beam. In any event, this again underscores the need for Qualcomm to provide three-dimensional GS antenna pattern masks in order to perform a proper sharing analysis.

Table 1 of Qualcomm's analysis in its July 31, 2012 Reply Comments shows a situation where a single VSAT is located 0.55 km away from the GS station. The analysis shows a  $C/(N+I)$  of -8.8 dB, or only a 0.2 dB margin against of Qualcomm's stated required performance for its lowest throughput. However, Qualcomm's analysis assumes an astounding blockage attenuation of 27.5 dB in order to show that their return link barely closes. This level of assumed blockage attenuation simply is not warranted given the small 550 meter distance between the two antennas.

#### Summary:

Our analyses for the two scenarios presented are admittedly not exhaustive. A full and proper analysis would account for varying VSAT heights, various distances between GS and VSAT antennas, multiple interfering VSATs with various VSAT-to-GS antenna gain couplings, trans-horizon (i.e., non-line-of-sight) VSAT interference into the GS sites as well as GS-to-GS trans-horizon interference.

Nonetheless, while we have not demonstrated the non-viability of the ATG return link in every conceivable circumstance (i.e., for 100 percent of all ATG GS sites), the two cases presented demonstrate that a single VSAT can completely disrupt the ATG return link. Considering the high negative  $C/(N+I)$  values calculated from a just single interfering VSAT, coupled with the large number of currently deployed VSATs within CONUS, it is difficult to understand Qualcomm's optimism that all of its 150-250 GS sites could be sited so as to avoid VSAT interference, especially considering GS sites will generally point north, while VSATs generally point south. Further, any GS installation would need to accept the risk and uncertainty that a future VSAT(s) would be deployed in its immediate vicinity.

#### 4.0 Interference from VSATs to ATG Aircraft

In order to calculate the potential interference into an ATG forward link, it is first necessary to estimate the number of VSAT's that are visible to an aircraft assumed to be flying at an altitude of 10 km.

The Satellite Industry Association ("SIA") is on record as stating there are 600,000 VSATs located in the United States and the number continues to grow. The bandwidth of the ATG forward link is 50 MHz. Therefore the number of VSATs transmitting in any 50 MHz of the 14.0-14.5 GHz 500 MHz band can be calculated to be  $600,000 \times 50 / 500$  or 60,000 VSATs. This number must be divided by the ratio of the surface area of CONUS to the surface area seen by an aircraft flying at an altitude of 10 km. The distance from an aircraft at an altitude of 10 km to the horizon is 357.3 km. Using this distance, the ratio of the total surface area of CONUS to the surface area seen by the aircraft can be calculated to be 20.2. Note that Qualcomm calculates a ratio of 28.6, but this is based on the ATG service area of 300 km and not the actual surface area of the Earth that can be seen from an aircraft flying at an altitude of 10 km (i.e., 300 km versus 357.3 km).

Using the proper ratio, the total number of VSATs in any particular 50 MHz of spectrum that can be seen by an aircraft can be calculated to be 2971. Assuming 25% of these VSATs transmit simultaneously, the number of interfering VSATs is reduced to 743.

All of the proceeding calculations have assumed a uniformity of distribution, or averaging. Obviously in a particular CONUS geographical area, where there is a higher population density, the number of VSATs will be accordingly increased.

Table 3 shows the calculation results of multiple VSATs interfering into the ATG aircraft receiver. The following assumptions were used:

- All VSATs are assumed to be transmitting at the maximum level provided by Section 25.134 of the FCC rules for routine licensing.
- All VSATs are assumed to be transmitting a 2 MHz carrier.
- The average path loss across the Earth's spherical cap as seen by an aircraft at 10 km was calculated to be 161.8 dB, which corresponds to an average distance of 206 km between the VSATs and the aircraft.
- The average gain coupling between VSATs antennas and the ATG aircraft antenna was taken to be 9.2 dB, which is a value derived by Qualcomm. Qualcomm states that the average gain coupling loss is 49 dB based on its simulations. The peak gain of a 1.2 meter VSAT antenna at 14.25 GHz is 43.2 dBi. The peak gain of the ATG aircraft antenna is

15 dBi. Therefore the average antenna gain coupling using Qualcomm's number is:  
 $43.2 + 15 - 49 = 9.2$  dBi.

Qualcomm states that its forward link for maximum throughput requires a minimum C/(N+I) of 4 dB. Table 3 demonstrates that the ATG forward link cannot achieve this C/(N+I) level for the given assumptions. Note that if it were assumed the population density of the VSATs were doubled in geographic areas with a higher population density, the ATG C/(N+I) would be reduced to -5.5dB.

Qualcomm states that its ATG network will use an adaptive air interface that can adjust the throughput rate according to the received C/I. However, Qualcomm does not state its lowest C/(N+I) requirement for its forward link, and more importantly, one in which the reduced throughput allows for a viable service.

Table 3. Multiple VSATs interfering into an ATG aircraft.

Parameter	Value	Units	Comments
Frequency	14.25	GHz	
Average Distance	206	km	
FSS Tx Input Power Density	-50	dBW/Hz	Section 25.134 of FCC rules
Number VSATs	743		
Average Gain Coupling	9.2	dB	Qualcomm's number
Average Free Space Path Loss	161.8	dB	
Average Atmospheric Loss	0.1	dB	
Polarization Mismatch	0	dB	
Aircraft Receiver Noise Temperature	631	K	
ATG Forward Link Bandwidth	77	dB-Hz	
Boltzmann Constant	228.6	dB/K/Hz	
I/N of FSS interferer at Aircraft	12.6	dB	High I/N
ATG C/N	10.2	dB	
C/I	-2.4	dB	
C/(N+I)	-2.6	dB	Conclusion: Either no ATG forward link service or reduced ATG throughput.

The preceding shows the case of multiple interfering VSATs with a low level of average antenna gain coupling. While we have used Qualcomm's value for the average gain coupling, we have not performed our own simulations to verify the value's accuracy.

While not contained herein, it can be shown that an ATG aircraft flying through the main beam of a single VSAT transmitting a 2 MHz wide carrier causes a C/(N+I) to the ATG forward link of less than -29dB. While this high level of interference would be short-lived due to the speed of the aircraft, Qualcomm states that its OFDM modulation technique could error-correct for a portion of the time the aircraft traverses the VSAT main beam since a single narrowband VSAT

interferer would only impact a number of OFDM frequency tones. However, as demonstrated in Table 3, the effect of multiple interfering VSATs across the 50 MHz bandwidth of the ATG forward link reduce the error-correction capability since all tones will be negatively impacted from multiple interfering VSATs. Again, the question becomes what is the lowest forward link  $C/(N+I)$ , and its associated throughput to the user, that allows for a viable service?

Finally, it should be noted that the above only accounts for VSAT interference. It does not account for other types of FSS interference such as Hub stations, backhaul stations, etc., which generally transmit wideband carriers and can be expected to be transmitting for a majority of the time. At a minimum, these non-VSAT FSS stations will increase the interference environment above that calculated in Table 3. There will also be additional interference from AMSS aircraft as discussed in section 5.

## 5.0 AMSS Interference into ATG Aircraft

Table 4 shows the results of a single AMSS equipped aircraft interfering into an ATG equipped aircraft. The following assumptions were used:

- The two aircraft are separated by 3000 feet.
- The assumed AMSS input power was taken from ROW 44's FCC license.
- The AMSS antenna has a 0 dBi gain towards the ATG antenna.
- The ATG antenna has a 0 dBi gain towards the AMSS antenna.

Table 4. Single AMSS interfering into an ATG aircraft.

Parameter	Value	Units	Comments
Frequency	14.25	GHz	
Distance	0.92	km	3000 feet separation between aircraft
AMSS Tx Input Power	13	dBW	ROW 44 Remote 2
AMSS Antenna Gain towards ATG Aircraft	0	dBi	28.8 dB down from peak gain
ATG Aircraft Antenna Gain towards AMSS	0	dBi	Qualcomm's lowest stated gain in azimuth
Free Space Path Loss	114.8	dB	
Atmospheric Loss	0.01	dB	
Polarization Mismatch	0	dB	
Aircraft Receiver Noise Temperature	631	K	
ATG Forward Link Bandwidth	77	dB-Hz	
Boltzmann Constant	228.6	dB/K/Hz	
I/N of AMSS interferer at Aircraft	21.8	dB	
ATG C/N	10.2	dB	
C/I	-11.6	dB	
C/(N+I)	-11.6	dB	Conclusion: ATG forward link disrupted

Table 4 shows that a single AMSS aircraft has the potential to disrupt the ATG's forward link. Note that the assumption of 0 dBi gain coupling between the two antennas is quite conservative. With this assumption, it would require a separation distance between the two aircraft of 6.3 km (approximately 4 miles) in order for the ATG forward link to achieve a C/(N+I) of 4 dB.

Note that we have not made any assumptions regarding the relative orientation between the two aircraft, relative directions or relative speeds, nor have we considered multiple interfering AMSS aircraft. While in many cases, the interference into an ATG aircraft will be transient, one can easily contemplate scenarios where the interference could last for the majority of the ATG flight. A simple example is where the AMSS aircraft is slightly below a nearby ATG aircraft and both are flying in the same general direction and at the same speed. It is important to note that the AMSS antenna is on top of the aircraft, while the ATG antenna is on the bottom of the aircraft. Therefore the AMSS aircraft could be at any lateral orientation or at any aft/starboard orientation relative to the ATG aircraft, and the ATG link will be disrupted. Obviously being both below and to the south of the ATG aircraft exacerbates the problem.

## 6.0 AMSS Interference into ATG Ground Station

Table 5 shows the results of a single AMSS equipped aircraft interfering into the ATG GS. The following assumptions were used:

- The assumed AMSS input power was taken from ROW 44's FCC license.
- The AMSS antenna has a 0 dBi gain towards the ATG GS.
- The GS antenna has a 34dBi gain towards the AMSS aircraft.

Table 5. Single AMSS interfering into an ATG ground station.

Parameter	Value	Units	Comments
Frequency	14.25	GHz	
Distance	300	km	Distance to AMSS aircraft
AMSS Tx Input Power	13.0	dBW	ROW 44 Remote 2
AMSS Gain towards GS	0	dBi	28.8 dB down from peak gain
GS Antenna Gain	34	dBi	3 dB down from peak gain
Free Space Path Loss	165.1	dB	
Atmospheric Loss	3	dB	
Polarization Mismatch	0	dB	
GS Receiver Noise Temperature	794	K	
AMSS Bandwidth	65	dB-Hz	
ATG Bandwidth	63	dB-Hz	
Boltzmann Constant	228.6	dB/K/Hz	
I/N of AMSS interferer at GS	19.5	dB	
ATG C/N	8.7	dB	
C/I	-10.8	dB	
C/(N+I)	-10.8	dB	Conclusion: ATG return link disrupted

Table 5 shows that a single AMSS aircraft has the potential to disrupt the ATG's return link.

Since the GS antenna is pointed towards the sky, it's reasonable to assume that one or more AMSS aircraft could be visible to the GS antenna. In the scenario presented, the AMSS aircraft is assumed to be 300 km away from the GS antenna. If we had assumed the AMSS aircraft was 150 km from the GS antenna, the path loss would decrease by 6 dB (i.e.,  $20 \cdot \log(\text{distance})$ ) and hence the interference would increase by 6 dB. However, Qualcomm states that the GS antenna has an isoflux pattern in elevation. Presumably this antenna rolls off at the same  $20 \cdot \log(\text{distance})$  rate as the elevation angle towards the sky increases. If this is the case, then the decreased path loss and decreased GS antenna gain would cancel each other out, and thus the only increase in interference between the 300 km distance case and a shorter distance results from the decrease in atmospheric loss.

Again, the AMSS interference could be transient in nature, but consider the case where an AMSS aircraft and an ATG aircraft are travelling in the same direction (e.g., east-to-west), they are separated in latitude (i.e., one is further north), but are at the same, or nearly same, longitude and travelling at the same speed. In such a case, both aircraft types are seen by the GS station(s) during the course of the flights, which would mean continuous interference into the ATG return link.

## **7.0 Conclusions**

This report has demonstrated the non-viability of an ATG service in the 14-14.5 GHz band due to interference from co-primary FSS as well as secondary AMSS. The technical analyses demonstrate the following main points:

- There is a real potential for interference from a single VSAT into an ATG return link. Multiple VSATs located in the vicinity of the ATG GS will exacerbate the problem. The ATG system cannot function without a reliable return link. Given the large number of currently deployed VSATs within CONUS, plus the fact that GS sites would generally point north, while VSATs generally point south, it is expected to be extremely difficult to find GS sites that are sufficiently free from VSAT interference. Further, any GS installation would need to accept the risk and uncertainty that a future VSAT(s), or other type of FSS earth station(s), would be deployed in its immediate vicinity.
- The ATG forward link either cannot successfully operate due to the combined interference received from multiple VSATs and multiple non-VSAT FSS transmissions that will be visible from an ATG aircraft antenna, or at a minimum, its throughput will be reduced relative to Qualcomm's assessment.



- An ATG aircraft's forward link can be disrupted by or experience long-term interference from a single AMSS aircraft. The antenna gain coupling assumption that was used in reaching this conclusion is quite conservative. Multiple AMSS aircraft would increase the likelihood of repeated disruptions or long-term interference.
- An ATG return link can be disrupted by or experience long-term interference from a single AMSS aircraft. Multiple AMSS aircraft would only increase the likelihood of repeated disruptions or long-term interference.

Given these conclusions, it is deemed that an ATG service could not offer a viable service using the 14-14.5 GHz band. Following proper spectrum management principles, the FCC should not allocate a secondary service if the interference environment from an existing co-primary and/or secondary service demonstrates that the proposed service is not viable.

Finally, and in the event the FCC was to pursue the idea of an ATG service in the 14-14.5 GHz band, three-dimensional ATG antenna pattern masks, both GS and aircraft antennas, would be required to perform proper sharing analyses.

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Prepared by:

Stephen D. McNeil  
Director, Spectrum and Regulatory Engineering  
Telecomm Strategies  
SteveM@TelecommStrategies.com  
(613) 270-1177